PATENT SPECIFICATION

817,943

Date of Application and filing Complete Specification: Jan. 8, 1957.
No. 676/57.
Application made in United States of America on Jan. 9, 1956.
Application made in United States of America on Feb. 3, 1956.
Complete Specification Published: Aug. 6, 1959.

Index at acceptance:—Classes 108(2), D2A1B; **108(3),** S8M1B; **and 144(2),** C(1X:9:10).

International Classification:—B62d, g. F06f.

COMPLETE SPECIFICATION

Pneumatic Load Bearing Devices

I, THOMAS ALFRED OTTO GROSS, of Concord Road, R.F.D., South Lincoln, Massachusetts, United States of America, a Citizen of the United States of America, do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to pneumatic load bearing devices, such as pneumatic tires, pneumatic springs and the like, which depend upon a gas under pressure to provide an elastic yielding support.

Pneumatic devices of this type are widely used to support a load with a cushioning action to protect it against shocks or jolts. Their operation is dependent largely upon the fact that the gas is compressible such that its volume may be reduced with an accompanying rise in pressure. A counteracting factor generally encountered, however, is the temperature rise accompanying the compression by which the pressure is raised disproportionately to the volume decrease and in excess of the pressure that would be developed under isothermal conditions.

The present invention provides a pneumatic load bearing device in which the temperature rise accompanying compression is minimized or otherwise controlled so that any given volume change is accompanied by a smaller pressure change. Conversely, in the pneumatic load bearing devices of this invention, a given pressure change, due for instance to a sudden shock, is effected with a greater volume change than in similar devices presently known. The result is a softer support, or greater cushioning action, which when applied to pneumatic tires gives a ride that is much smoother, and when applied to pneumatic springs gives greater compliance to sudden displacements.

One conception of the invention consists in providing a solid material which serves as a thermal reservoir, or heat sink, intimately distributed substantially throughout the volume of gas in an amount such that its heat capacity (mass times specific heat) is large in relation to the heat capacity of the gas. This solid material serves to equalize the temperature normally accompanying compression and expansion through the exchange of heat between it and the gas. Accordingly the solid material is distributed to present a large extended surface in intimate heat exchange relation with the gas such that the rate of heat exchange is sufficient to maintain the temperature of the gas substantially constant during compression and expansion. By virtue of this exchange volume changes which are normally adiabatic occur substantially isothermally.

The amount of the solid material will depend chiefly on the desired degree to which the temperature of the gas is to be held constant, and the distribution of the solid material will depend chifly on the rate at which heat is to be exchanged. Where less than maximum temperature equalization is to be had, smaller amounts of solid material may be used and it may be distributed less extensively and with less surface available for heat exchange than when better temperature equalization is sought. Similarly, where the rate of compression or expansion is low, the distribution of the solid material and the surface available for heat exchange may be such that the rate of heat exchange is low, but where compression and expansion occur rapidly the surface must be large and so distributed throughout the gas that the rate of exchange occurs at a much higher rate.

Conditions under which cushion support of the type provided by pneumatic load bearing devices is effectively used generally include shocks and jolts producing rapid compressions and expansion, and it is with reference to such conditions that the preferred embodiments of this invention are described. In particular, the conditions encountered in providing pneumatic yielding support for vehicles are considered typical.

To realize best results the total heat capacity

of the solid material is greater than the heat capacity of the gas, preferably more than five times the heat capacity of the gas, and is distributed such that substantially all the heat accompanying compression or expansion, for instance 75% or more, is exchanged within a time which is very short in relation to the duration of compression or expansion, typically less than about 10 milliseconds (0.01 second). To achieve this result, the heat sink is distributed to provide a surface for heat exchange in close proximity to substantially all of the inflating gas. Desirably the solid material is distributed so that at least 30%, and preferably at least 70%, of the volume of gas is situated within 0.1 centimeter, and preferably within 0.05 centimeter, of the nearest portion of surface to which heat may be exchanged.

Suitable solid materials will accordingly be any of a number of substances which may be formed with large surfaces and which have relatively high heat capacities and thermal conductivities. The material may, for instance, be fine fibers of glass, metal or other material having the necessary capacity, distributed in either a random or oriented manner throughout the gas, or it may be fine particles of the solid material dispersed throughout the gas to present the desired amount and distribution of surface. Cellular materials, such as solid foam substances having small, preferably open walled, cells may also be used.

In arranging the solid material throughout the volume of gas, it is generally preferred that the solid material not interfere with the pneumatic support provided by the gas, and in particular the solid material need not function to bear any substantial part of the load. Although numerous obvious ways of arranging and distributing the solid material throughout the gas may be used, the preferred methods consist in arranging fine fibers of solid materials, such as glass or metal, in close parallel proximity, as by embedding their ends in a supporting base, and supporting them in this manner within the volume of gas. Another very suitable technique consists in suspending fine solid particles in the gas as by mechanical agitation. Both of these permit most effective utilization and distribution of the surface of the solid material, with an optimum amount of solid material such that an excessive fraction of the volume is not filled with solid material to the exclusion of gas. In this connection, while the heat capacity of the solid is desirably high in relation to the heat capacity of the gas, an excessive amount of solid material, for instance an amount providing a heat capacity in excess of 20 times the capacity of the gas, provides only slight additional benefit from absorbing additional heat, and that at the expense of occupying volume that would better be utilized if occupied by gas. Thus, as a practical matter, the solid material is not advantageously used in an amount such that its capacity is in excess of about 20 times that of the gas.

This invention also contemplates another way of providing an improved pneumatic load bearing device, namely through the use of inflating gases which have large complex molecules with large and easily excited spin and/or torsional moments. Such gases are generally halogen-carbon compounds and other halide gases, particularly fluorides. When subjected to a sudden compressive force, they have been found to permit much greater volume changes for a given pressure rise than gases heretofore used. Stated conversely, such gases show a smaller pressure rise for a given sudden volume change.

An investigation of the behavior of these gases and the condition of them under suddenly applied loads, reveals that the physical constant expressive of the combined qualities of molecular degrees of freedom and other dimensions rendering pressure changes less responsive to volume changes is the ratio of specific heat at constant pressure, Cp, to specific heat at constant volume, Cv, the ratio being generally designated by the symbol γ. The improved results I have discovered are best achieved with gases having a γ of less than about 1.25. A representative number of such gases are set forth in Table I. Improved results are, however, realized with any gas having a γ value substantially less than that of air, carbon dioxide and other gases heretofore used, the γ value of which have consistently been below 1.4.

TABLE I

Low Gas Compounds	Formula	Boiling Point °C.		Cp/Cv
		1 atm	5 atm	1 atm 30° C.
Carbon tetrachloride	CCl_4	77	142	1.12 (1)
Trichlorofluoromethane	CCl_3F	24	77	1.14
Dichlorodifluoromethane	CCl_2F_2	30	16	1.14
Dichlorofluoromethane	$CHCl_2F$	9	59	1.17

TABLE I

Low Gas Compounds	Formula	Boiling Point °C.		Cp/Cv
		1 atm	5 atm	1 atm 30° C.
Chlorobromodifluoromethane	$CClBrF_2$	−3	47	1.13
Trichloromethane	$CHCl_3$	62	120	
Methyl bromide	CH_3Br	5	55	1.24
Octafluorocyclobutane	C_4F_8	−7	40	
Dichlorotetrafluoroethane	$CClF_2—CClF_2$	4	56	1.09
Trichlorotrifluoroethane	$CCl_2F—CClF_2$	47	105	1.08 (2)
Tetrachlorodifluoroethane	$CCl_2F—CCl_2F$	93	150	
Chlorotrifluoroethylene	$CClF—CF_2$	−28	16	
Dibromodifluoromethane	CBr_2F_2	25	82	1.12
Dibromotetrafluoroethane	$CBrF_2—CBrF_2$	47	106	
Bromochloromethane	CH_2BrCl	67		1.19
Chlorotrifluoromethane	$CClF_3$	−81	−43	1.17 (3)
Chlorodifluoromethane	$CHClF_2$	−41	0	1.18
Methyl fluoride	CH_3F	−79	−42	
Tetrafluoromethane	CF_4		−100	1.22 (4)
Chloropentafluoroethane	$CClF_2—CF_3$	−38	5	1.09
Perfluoroethane	$CF_3—CF_3$	−78	−52	
Perfluoroethylene	$CF_2:CF_2$	−78		
Difluoroethylene	$CH_2:CF_2$			
Trifluoromethane	CHF_3	−82		
Vinyl fluoride	$CH_2:CHF$	−51		
Sulfurhexafluoride	SF_6	−65	−30	1.09
Borontrifluoride	BF_3	−101	−73	
Monobromotrifluoromethane	$CBrF_3$		−17	1.14

(1) at 80° C.
(2) at 60° C.
(3) at 30° C.
(4) at 80° C.

Accordingly, the invention may be embodied in pneumatic tires and similar devices by inflating them with a gas having a γ of less than 1.25, for instance with sulfur hexafluoride, hexafluoroethane, or other low gamma gas having a vapor pressure in excess of the inflation pressure at operating temperatures.

The effect of such inflation has been tested and found to be demonstrable in giving a noticeably smoother ride on rough surfaces without resulting in the adverse effects of under-inflation of the tires. The tires are inflated to the recommended static pressure, e.g. 26 psi. The effects of using a low γ gas are realized under compression conditions during which these gases undergo a greater volume change for a given pressure increase, or, conversely, show a lower pressure rise for a given volume change.

The reason for this behavior is believed to lie in the fact that sudden compressions of this sort are substantially adiabatic, that is to say there is no heat exchange to or from the gas. The temperature rise that accompanies compression is accordingly not compensated by loss of heat to the surroundings, and serves to resist the pressure increase. With a low γ gas, the temperature rise is less than with a gas having a higher γ and the low γ gas is accordingly more compressible under adiabatic conditions. The relationship can be readily appreciated from the classical formula for the pressure-volume relationship of gases under adiabatic conditions.

$$P_1 = Po \left(\frac{V_0}{V_1} \right)^{\gamma}$$

where P_0 = an initial pressure,
V_0 = an initial volume,
V_1 = a final volume,
P_1 = a final pressure, and
γ = the ratio of specific heat at constant pressure to specific heat at constant volume.

From the foregoing it will be seen that under the substantially adiabatic conditions which are seen to prevail in pressure-volume changes occurring in a pneumatic tire in actual use on rough surfaces, increased compliance of the inflating gas to external shocks will be realized while the static inflating pressure is the same as when air is used for inflation.

Numerous of the gases listed in Table I may be used. Sulfur hexafluoride is particularly useful as a low γ inflating medium, since it has a high vapor pressure (5 atm. at $-30°$ C.), is extremely inert to rubber, and has a γ value of 1.09 at 30° C. Other gases such as C_2F_6, CF_3 Br and $C\,Cl_2F_2$ and other fluorine-carbon compounds may also be used. Some of these, such as $C\,Cl_2F_2$ have a tendency to attack rubber, but this effect can be avoided by incorporating a liner of a material that is not atacked by the gas as a barrier between the gas and tire.

Suitable barrier materials include polyethylene, plasticized vinyl chloride, polyvinyl alcohol, polymerized tetrafluoroethylene and other flexible plastic materials which are inert and impervious to such gases. The recent advent of so-called tubeless tires which are inflated directly without the use of an inner tube, provides a particularly convenient means of incorporating a liner which may be a separate preformed structure lying in contact with the inner surface of the tire, or may be a coating of the barrier material applied to the inner surface of the tire. Inasmuch as the art in this field is well developed it is not seen that a description of the details involved in providing a suitable liner will in any way enhance an understanding of the invention.

The invention is not limited to the use in pneumatic load bearing devices of inflating media that are inherently gaseous under normal conditions. Where elevated temperatures are encountered materials that are gases at such temperatures, although they may be liquids at ordinary temperatures, may be used. Carbon tetrachloride and other such normally liquid substances, are listed in Table I.

The use of normally liquid substances having vapors of low γ also provides a convenient means of varying the load carrying capacity of such devices by employing heating means to develop the desired vapor pressure. One application of this principle lies in a pneumatic spring employing a low γ gas as the inflating fluid. By utilizing a liquid having vapors of the desired low γ, the inflating pressure may be easily varied proportionately to the load by providing a heating element adjustable according to the load. Such adjustment could be manual, or it could be acomplished by means of a variable control member which is itself responsive to the load.

An embodiment of the invention featuring this principle typically consists of an enclosed container having movable wall portions by which the load is carried, such as provided by a bellows or by a cylinder having a close fitting piston. The container is inflated under the pressure of a vapor of a liquid contained within it in contact with a heating element by which the vapor pressure may be varied.

In this manner a variable load bearing characteristics may be enjoyed simply by varying the heating of the liquid.

Additional pneumatic support may also be provided by adding to the vapor a low γ gas which does not condense at the ambient temperature and internal pressure. Such serves conveniently as a residual cushion assuring pneumatic support under all conditions, even when the vaporizable material is

entirely liquid. In vehicle springs, for instance, such a gas provides pneumatic suspension at startup, before the heating element has come up to a temperature at which the desired vapor pressure is developed.

Typical embodiments of this invention as applied specifically to pneumatic tires and to a pneumatic spring are described below with reference to the accompanying drawing in which:—

Figure 1 is a view in side elevation showing a pneumatic tire embodying the invention, with portions cut away to reveal structural details,

Figure 2 is a cross-sectional view through the tire shown in Figure 1, and

Figure 3 is a schematic cross-sectional showing a preferred manner by which a pneumatic spring may be constructed in accordance with this invention.

A pneumatic tired vehicle embodying this invention is shown in Figures 1 and 2. The tire 10, preferably one of the common tubeless variety, is mounted in the usual manner to the wheel rim 12 about a preferred type of heat sink member 14 which provides an extended surface of solid material distributed substantially throughout the volume of the tire. The tire is inflated with air in the usual manner.

The heat sink member 14 consists of closely parallel glass fibers 16 having one of their ends held in a base band 18 which is wrapped around the wheel rim 12 to support the fibers in a generally radial array extending substantially through the inside of the tire. The fibers 16 may be secured to the base band 18 by any of numerous well-known methods, for instance the base band 18 may be fabric to which the fibers 16 are attached in the manner of a deep pile. Alternatively, the base band may be of a molded plastic material such as rubber in which the ends of the fibers have been embedded.

The glass fibers are extremely fine and very closely distributed such that their total mass has a heat capacity of roughly about five times the capacity of the inflating gas, and the surface of the fibers is distributed intimately throughout the gas so that the heat is substantially entirely exchanged within about 1 millisecond following a compression or expansion.

Glass fibers of size G (average diameter= 0.001 cm.) packed at a density of 10,000 per sq. cm. are entirely suitable as the solid heat sink, providing under these conditions a heat capacity of about five times that of the inflating air and a distribution of surface such that the average maximum distance from any point within the aray of fibers to a fiber surface is about .005 cm.

This arrangement of the heat sink fibers is particularly advantageous since the fibers are out of contact with the inner surface of the tread portion of the tire, and are held radially extended by the centrifugal force of the rotation of the wheel. Thus, the orientation and distribution of the fibers is held fairly well fixed without permanent dislocation or bunching, which would interfere with the optimal operation of the heat sink material.

The effect of providing a heat sink within a tire of this type is a noticeably smoother ride at any given static inflation pressure, since under compression and expansion from road surface iregularities, the volume change occurring is considerably greater than when air alone is used.

In Figure 3 is shown an embodiment of this invention as applied to a pneumatic spring 20 supporting a vehicle chasiss 22 upon an axle 24. The spring 20 is shown as comprising a bellows 26, closed at both ends by cover members 28 and 30 which are secured respectively to the chassis 22 and axle 24. The solid heat sink material is distributed within the bellows 26 in the form of fine particles 32 of pulverulent solid material, the amount being sufficient to provide a heat capacity between about 1 and 20 times the heat capacity of the inflating gas, and the particle size being such that the material may be evenly suspended in the gas with 30% or more of the gas volume within 0.1 cm. or less of particle surface.

Continuous suspension of the particles in the embodiment shown is provided by a fan 34 mounted within the bellows, and driven by a small electric motor 35 supported on an appropriate bracket 36.

In a spring of this type designed for use in vehicle suspension systems, a suitable solid material is powdered talc passing a 1000 mash Tyler screen, in an amount of about 30 grams per liter of spring volume, for the case of air at 50 psi as the inflating gas.

Another satisfactory material is finely divided molybdenum sulfide, MoS_2, which is available as particles having an average size of the order of a micron, for instance the material designated " Molycoat " and sold by Alpha Corp., of Stamford, Connecticut.

WHAT I CLAIM IS:—

1. A pneumatic load bearing device in which provision is made for ensuring that pressure volume changes in the load bearing gas occur substantially isothermally either by filling the space for the load bearing gas with a gas or a mixture of gases having a ratio of specific heat at constant pressure (C.p.) to epecific heat at constant volume (C.v.) which is less than 1.4 so that on compression the temperature of the gas remains substantially constant during volume change or by intimately distributing within the gas containing space of said device a solid material having a heat capacity which is large in relation to the heat capacity of the gas

which is to be introduced into said space to bear the load and which presents a surface area distributed in intimate exchange relationship with the gas such that the heat accompanying volume changes of the gas is exchanged with the solid material at a rate such that on compression the temperature of the gas remains substantially constant during volume change.

2. A pneumatic load bearing device accordin to claim 1 in which the load bearing gas is introduced in the form of a liquid having a vapor pressure effective to support the load and such that the gas has a ratio of specific heat at constant pressure (C.p.) to specific heat at constant volume (C.v.) which is such that on compression the temperature of the gas remains substantially constant during volume change.

3. A pneumatic load bearing device according to claim 1 in which the surface area of the material is presented to the gas so that at least 30% of the gas is situated within 0.1 centimetres of solid surface.

4. A pneumatic load bearing device according to claim 1 in which the surface area of the material is presented to the gas so that at least 70% of the gas is situated within 0.05 centimetre of solid surface.

5. A pneumatic load bearing device according to claim 1 in which the solid material presents a surface area such that approximately 75% of the heat accompanying a volume change in the gas is absorbed by the solid material within less than 0.01 second thereby ensuring that a volume change occurs substantially isothermally.

6. A pneumatic load bearing device according to any one of the preceding claims 1, 3, 4 and 5 in which the solid material is in the form of fibres.

7. A pneumatic load bearing device according to any one of the preceding claims 1, 3, 4 and 5 in which the solid material is in the form of a dispersible solid particulate matter.

8. A pneumatic load bearing device according to claim 6 in which the fibres are attached to a base adapted to be located within the gas containing space.

9. A pneumatic load bearing device according to claim 7 in which the solid solid material is in the form of particles of pulverulent solid material in an amount sufficient to provide a heat capacity between 1 and 20 times the heat capacity of the inflating gas and of a particle size such that the material may be evenly suspended within the gas with 30% or more of the gas volume within 0.1 centimetre or less of particle surface.

10. A pneumatic load bearing device according to claim 7 in which power operated means is provided for maintaining the particles dispersed within the gas.

11. A traction member incorporating a pneumatic tire adapted to be mounted on a wheel rim, and a solid heat sink comprising fibers of solid material adapted to be secured around said rim and substantially radially disposed within said tire, said fibers being in an amount such that their total heat capacity is large in relation to the gas with which the tire is to be inflated and presenting a surface area distributed in intimate heat exchange relation with said gas such that volume changes of the gas occur substantially isothermally through the exchange of heat between the gas and the fibers.

12. A pneumatic spring comprising a container having wall portions movable and effective to vary the volume of the container, a gas within said container under a pressure supporting said wall portions, and solid particulate material forming a heat sink dispersed in and intimately throughout said gas, said material having a heat capacity which is large in relation to the heat capacity of the gas and presenting a surface area distributed in intimate heat exchange relation with the gas such that the heat accompanying volume changes of the gas is exchanged with the solid material at a rate sufficient to maintain the temperature of the gas substanially consant during the volume change.

13. A pneumatic load bearing devicc according to claim 1 in which in the case of a load bearing gas or mixture of gases having the property specified the gas or mixture of gases has a ratio of C.p./C.v of 1.25.

14. A pneumatic load bearing device according to claim 2 in which the vapor has a ratio of C.p./C.v. which does not materially exceed 1.25.

15. A pneumatic load bearing device according to claim 2 in which heating means is provided for volatilizing the liquid introduced.

16. A pneumatic vehicle tire inflated with a gas having a ratio of C.p./C.v. of no more than 1.25.

17. A pneumatic spring comprising a vessel having movable wall portions effective to vary the volume of the vessel and to support a load tending to move said portions, and an inflating medium within said vessel comprising a gas under a pressure effective to support said load and having a ratio of C.p./C.v. of no more than 1.25.

18. A pneumatic spring comprising a vessel having movable wall portions effective to vary the volume of the vessel and to support a load tending to move said portions, heating means within said vessel and a volatile liquid within and partially filling said vessel and in contact with said heating means, the vapor of said liquid being at a pressure to support the load and having a ratio of C.p./C.v. of no more than 1.25.

19. A pneumatic load bearing device con-

structed and adapted for use substantially as herein described.

20. A pneumatic load bearing device constructed, arranged and adapted for use substantially as herein described with particular reference to Figures 1 and 2 of the accompanying drawings.

21. A pneumatic load bearing device constructed, arranged and adapted for use substantially as herein described with particular reference to Figure 3 of the accompanying drawings.

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Leamington Spa: Printed for Her Majesty's Stationery Office, by the Courier Press.—1959.
Published by The Patent Office, 25, Southampton Buildings, London, W.C.2, from which copies may be obtained.

817,943 COMPLETE SPECIFICATION
1 SHEET

This drawing is a reproduction of the Original on a reduced scale.

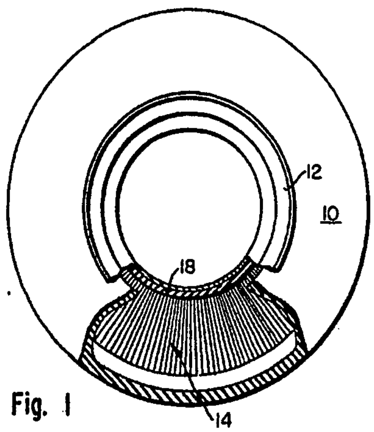

Fig. 1

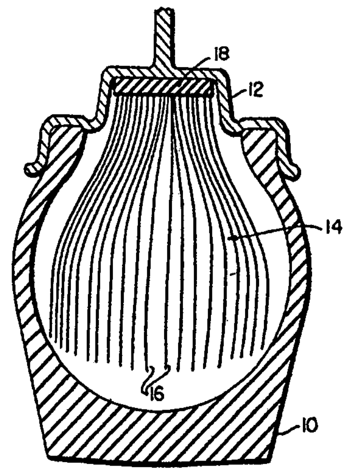

Fig. 2

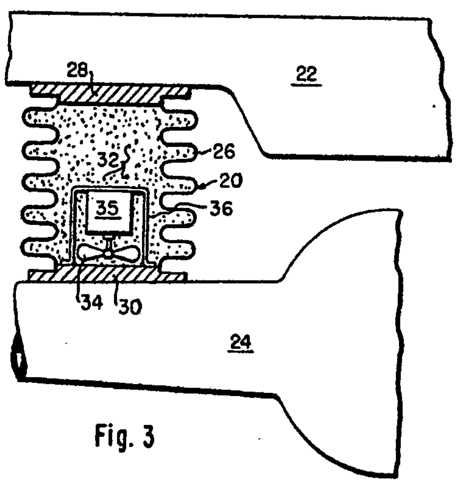

Fig. 3